# Optoelectronic Terahertz Sources Based on Photomixers

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## ABSTRACT

Molecular line observation in the THz region using heterodyne receivers is a powerful way to investigate the chemistry and physics of the interstellar medium. However, THz heterodyne observation's potential is far from being fully realized due to source-technology limitations. The available solid-state, CW sources with enough power to serve as local oscillators (LOs) above ~1 THz are currently limited to ~10% in bandwidth and 1.6 THz in maximum frequency. Additionally, the lack of high spectral purity, frequency-agile sources hinders laboratory spectroscopy, and receiver/component characterization. We are developing traveling-wave photomixers and laser systems to overcome these impediments. Our goals include providing space-borne LO technology for (HEB) mixers to over 3 THz and portable, automated signal sources for characterization of THz receivers/components as well as laboratory spectroscopy. The state of research will be presented along with discussions of requirements for THz LOs and laboratory test sources, and the photomixer approach's unique advantages.

## THZ LOCAL OSCILLATOR FOR HEB MIXERS ON SPACE-BORNE PLATFORMS

### Introduction

Of the four main promising CW, THz LO technologies (namely, multiplier chains based on solid state mm sources, multiplier chains based on backward wave oscillators, optically pumped far-IR lasers, and photomixers), photomixer is **the only approach that is both solid state and broadband.**

### Requirements

The following is a list of requirements and desired characteristics for THz, spaceborne, LOs:

1. Output power: At ~ 2 THz, **1 – 2 μW** arriving at the receiver front-end is adequate to optimally pump a Nb HEB mixer with ~ 8 GHz of IF bandwidth using a beamsplitter front-end.
2. Spatial pattern: need good mode-matching with mixer antenna and receiver front-end.
3. Linewidth, frequency stability and accuracy: For light molecules, **Doppler linewidth ~ $3 \times 10^{-6}$**, a frequency stability and accuracy of **$\Delta\nu/\nu = 3 \times 10^{-7}$** corresponds to a velocity discrimination of 0.1 km/s for light molecules.

4. Spectral coverage & tunability: Upcoming heterodyne instruments have the following spectral coverage: HIFI on Herschel, 0.48 – 1.91 THz; CASIMIR on SOFIA, 0.5 – 1.2 THz; GREAT on SOFIA, 1.2 – 4.0 THz. A typical, quasi-optically coupled (using a twin-slot antenna and a hyper-hemisphere), Nb HEB mixer setup has a spectral bandwidth of ~ 30%. Therefore, it is highly desirable to have a LO technology offering a spectral coverage up to **4 THz** and a tunability of **30%**.
5. Power consumption: generally speaking, ~ **10 W** or less.
6. Size & weight: need to be low for space-borne spectrometers.
7. Robustness: for space qualification.
8. Automation: essential for space-borne spectrometers.
9. Long-term reliability: need to operate **many years** on space-borne platforms.

**Past accomplishments and current status**

With respect to output *power* and *spatial pattern*, in 1999, Verghese *et al.* [ref] had already demonstrated the capability of the photomixerserving as a LO for a SIS receiver at 630 GHz. Of the 0.4 μW of sub-mm power, 0.2 μW was coupled into the receiver's spatial mode via a diplexer. Their measured DSB (double sideband) noise temperature of 331 K was comparable to the 323 K obtained when a Gunn oscillator based multiplier chain, generating 0.25 μW, replaced the photomixer. Currently, compared to solid state multiplier chains (the other solid state technology), the photomixer's output power [refs] does not show an advantage until frequencies exceed approximately 2 THz. Work is currently carried out at JPL to attain μW power levels up to 3 THz using improved designs based on a traveling-wave photomixer concept (see below) [ref].

With respect to *linewidth, frequency stability, frequency accuracy*, we have made strides at JPL/Caltech. In 1997, using resonant optical feedback to narrow the linewidth of the diode lasers that pump the photomixer, Chen *et al.* [ref] demonstrated a linewidth of 50 kHz without any electrical locking circuit. In order to overcome the problem of accurate frequency calibration and tuning, we devised and implemented a three-diode-laser pumping system to obtain a linewidth of 1 MHz ($1 \times 10^{-6}$ at 1 THz), as well as a frequency stability and accuracy of 200–300 kHz ($3 \times 10^{-7}$ at 1 THz)[refs].

With respect to *spectral coverage*, we have demonstrated impressive capabilities. Using the above-mentioned three-diode-laser system, we acquired high-resolution molecular spectra of ammonia and water from 0.2 to 1.6 THz without replacing any hardware component or major changes in hardware configuration. More recently, Matsuura *et al.* at JPL/Caltech devised a novel approach: the traveling-wave photomixer (TWP)[ref]. It is well known that the optical damage threshold ultimately limits the output power of a small area device. The easiest way to increase the optical damage threshold is to increase the device area. However, increasing the device area increases the device's capacitance (C), resulting in no net gain of output power for frequencies above ~ 1 THz. A TWP is capable of generating 10 dB more power than previous, small area, devices above 1.5 THz. This is because the RC time constant associated with the small area device is removed. Instead, the TWP requires the two optical beams to be incident at an angle, such that the velocity of the optical interference pattern matches the group velocity of the generated THz wave along the photomixer surface. Therefore, a large-area—*i.e.* distributed instead of lumped elememt—device is realized without paying the same penalty in bandwidth.

Mainly due to its solid-state nature, the photomixer has inherent advantages with respect to power consumption, size, weight, robustness, automation, and long-term stability. However, due to the fact that it is still at a laboratory developmental stage, these advantages are far from being fully materialized.

**Future directions**

Our photomixer expertise here fall in three general categories:

1) Frequency control of THz output. We developed a THz source that generates narrow linewidth (1 MHz) and accurately (250 kHz uncertainty) tunable radiation from 0.2 to 1.6 THz. Using this source, we have measured transition frequencies of ammonia and water in their ground and vibrationally excited states.

A possible future direction is to develop an automated version of this.

2) Traveling-wave photomixers (TWP). Here at JPL, we developed a novel kind of traveling-wave photomixer and measured 0.2 uW (coupled into the bolometer, not corrected for losses) of output from 0.6 to 2 THz from a singe device.

Currently, the velocity matching between the optical interference wave and the THz wave is achieved by varying the incidence angle between the two laser pump beams. A possible future direction is to develop a monolithically fiber-coupled TWP where the velocity matching is achieved through the design of device thickness and RF structure, and the optical waves are evanescently coupled from the fiber to the photomixer. This would provide a compact and robust THz source with very broad spectral coverage.

3) Long-wavelength photomixing material. In collaboration with Professor Gossard's group at UC Santa Barbara, we are developing photomixing material that can be pump by laser diodes operating at 1.5 um. The success of this research direction will allow the photomixer technology to exploit the rapid development in telecommunication lasers and related optoelectronics components. Prof. Gossard's group recently reported the successful growth of ErAs:InGaAs, and demonstrated promising electrical properties.

We would like the opportunity to test the optical properties of this material, as well as fabricating photomixers using this material and characterizing their THz performance.

## CONCLUSIONS

Despite the many desired features demonstrated and promised by the photomixer technology, its research an development has been a rapidly dwindling field in the past three years. In fact, to the authors' knowledge, we are the only group in the United States conducting photomixer research for applications in THz coherent detection. If NASA believes a solid state, broadband, frequency agile, THz source is worth investing in, now is the time, before the field disappears.